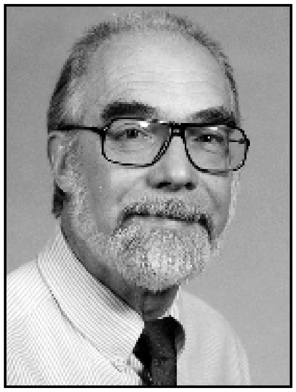
Development of Inexpensive Metal Alloy Electrodes for Cost-Competitive Solid Oxide Fuel Cells



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Objectives

- Develop and demonstrate a low-cost alternative to conventional anode-supported thin-film solid oxide fuel cell technology through the use of ferretic steel-supported cell architecture.
- Refine anode composition and microstructure for use with porous FeCr supports.
- Develop a cathode composition suitable for firing in reducing atmospheres and/or low-temperature bonding to the thin-film electrolyte.
- Demonstrate the weldability of porous FeCr support.
- Develop coating technology to prevent chromium evaporation from metal interconnects on the air of the SOFC.

Key Milestones

- Successfully engineered the porous FeCr support and the catalytic Ni-YSZ interlayer such that co-firing of the FeCr/Ni-YSZ/YSZ trilayer in a reducing atmosphere leads to a dense YSZ film supported on a inexpensive and mechanically robust stainless steel support.
- Developed a modified bilayer sintering procedure to avoid overdensification of the anode during firing of the FeCr/Ni-YSZ/YSZ trilayer.
- Demonstrated good electrochemical performance of the FeCr/Ni-YSZ/YSZ structure.
- Developed a unique coating for the stainless steel interconnect based on the reaction product of the LSM cathode and FeCr alloy to form an electronically conductive manganese chromium spinel.
- Successfully welded a stainless steel bolt to the base of a porous FeCr SOFC support, demonstrating the flexibility of seal design for this approach.

Approach

The development of anode and cathode supported thin-film electrolyte technology at the Lawrence Berkeley National Laboratory has allowed reduction of the operating temperature of solid oxide fuel cells to below 800 ^{o}C, enabling the use of metallic interconnects in the fuel cell stack. The Solid State Energy Conversion Alliance has defined a cost target of $400/kW for a 3- to 10-kW SOFC system module. Assuming the stack cost is a third of the system cost, the allowable cost for a fully engineered stack is $130/kW, which puts a ceiling on costs of materials and manufacturing technology for the SOFC stack. Accordingly, the LBNL group has introduced the concept of building the electrode-supported cell on a porous ferretic steel plate. This approach offers several advantages over Ni-YSZ supported cells, including lower raw materials costs, improved mechanical properties of the cell, increased flexibility in seal design, and stability of the anode towards oxidation. The combination of these advantages should result in a far lower SOFC stack cost, and simplified SOFC system design due to the redox stability of the anode. In order to realize such benefits, the LBNL group has developed fabrication technology for sintering the metal supported thin-film electrolyte cells. Technical hurdles include engineering the sintering profiles for the FeCr metal powder, the Ni-YSZ interlayer, and the YSZ thin-film so that the YSZ film is completely dense, while the FeCr support and Ni-YSZ interlayer maintain porosity for gas transport. Preliminary testing of the FeCr supported cells was started in $H_2(H_2O)$/air environment from 650 to 800 °C. The LBNL team also sintered FeCr/Ni-YSZ/FeCr trilayers to measure the electronic conductivity across the FeCr/Ni interface to determine the effect of redox cycling on the anode. Additionally, the LBNL team initiated studies on the stability of FeCr alloy on the air side of the SOFC, and is developing coating technology to prevent chromium volatilization. The LBNL group also installed a commercial tape-casting bench (metal support fabrication), a robotic aerosol spray unit (thin-film electrolyte deposition), and an automated screen printer (cathode deposition) to increase reproducibility of fuel cell fabrication and aid scale-up of the effort.

Results

The LBNL team successfully fabricated thin-film structures based on inexpensive porous stainless steel supports (FeCr/Ni-YSZ/YSZ). The sintering of FeCr, Ni-YSZ, and YSZ films were successfully engineered so that dense films of YSZ electrolytes were fired onto the porous supports under highly-reducing conditions. Preliminary testing of FeCr/Ni-YSZ/YSZ based fuel cells showed anode overpotentials consistent with SOFC performance targets. A number of porous FeCr electrode supports were successfully welded to stainless steel fittings, demonstrating that simplified seals were made possible with metal supported SOFCs. Results from oxidation/reduction cycling of FeCr/Ni-YSZ/FeCr structures demonstrated redox the stability of the FeCr substrate and FeCr/Ni interface. The LBNL team also determined that reaction of the lanthanum strontium manganate air electrode with the FeCr interconnect alloy leads to the formation of electronically conductive $MnCr_2O_4$ spinel at the interface. Since the $MnCr_2O_4$ spinel is stable against both FeCr and LSM, it may be an ideal coating for the air-side of the metal interconnect to prevent the volatilization of chromium.

Conclusions

Proof of concept for metal-supported solid oxide fuel cells has been demonstrated. While the performance of the metal supported SOFC is not yet at the levels attained by the LBNL group for Ni-YSZ supported cells, the metal-based SOFC performance is consistent with the commercial goals of the program. The ability to make welded connections and seals to the metal support also simplifies seal design for the stack. Preliminary results on manganese spinel coatings for metal interconnects imply that chromium volatilization on the air-side of the fuel cell can be prevented. The low cost of raw materials and the straightforward fabrication techniques developed at LBNL for metal supported SOFCs should meet the SECA cost targets for the fuel cell stack.

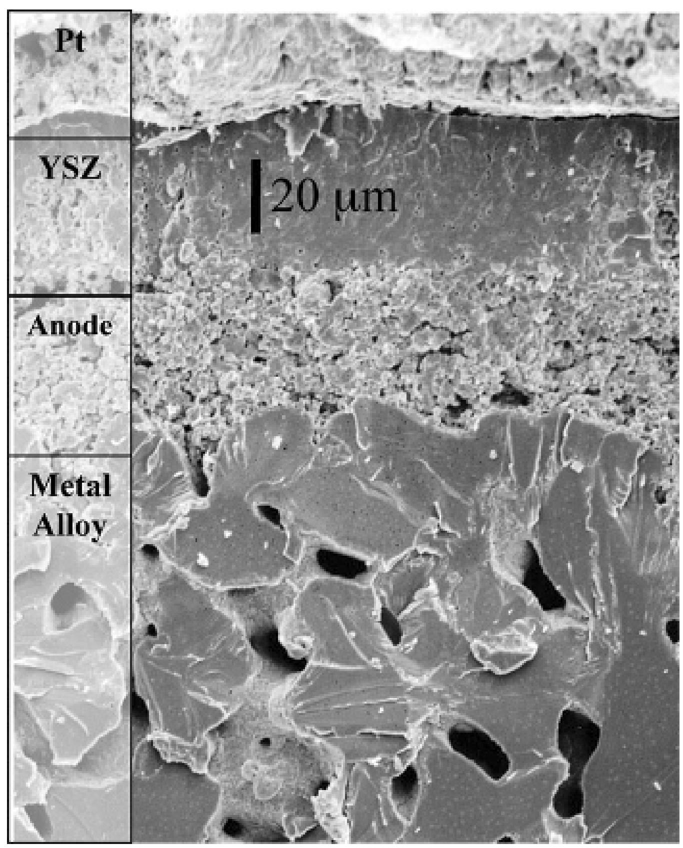

Figure 1: *Scanning electron micrograph (SEM) of fracture section of a metal supported thin-film solid oxide fuel cell.*

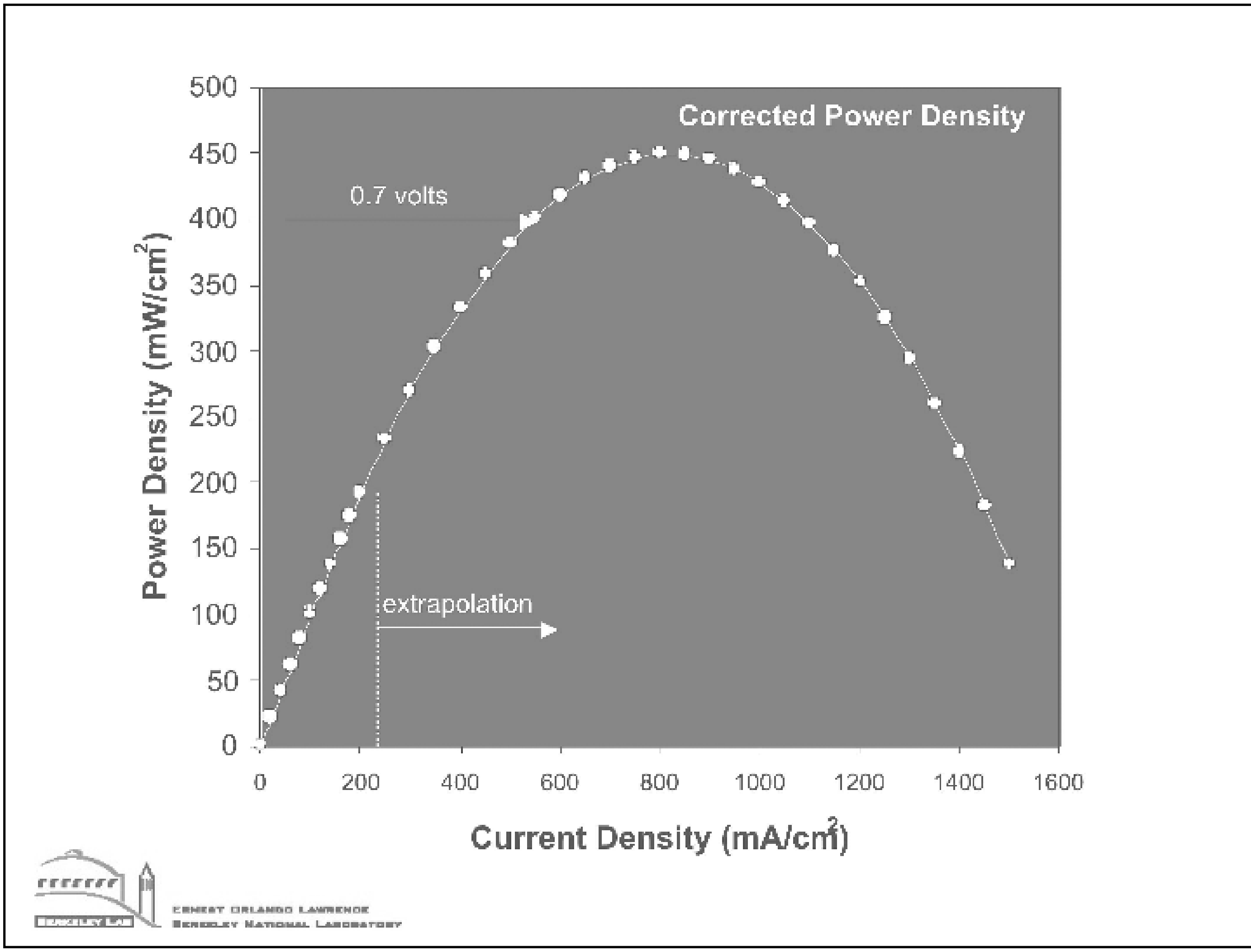

Figure 2: *Power density for FeCr/Ni-YSZ/YSZ based cell in H_2-H_2O/air at 800 °C (corrected for cathode polarization).*

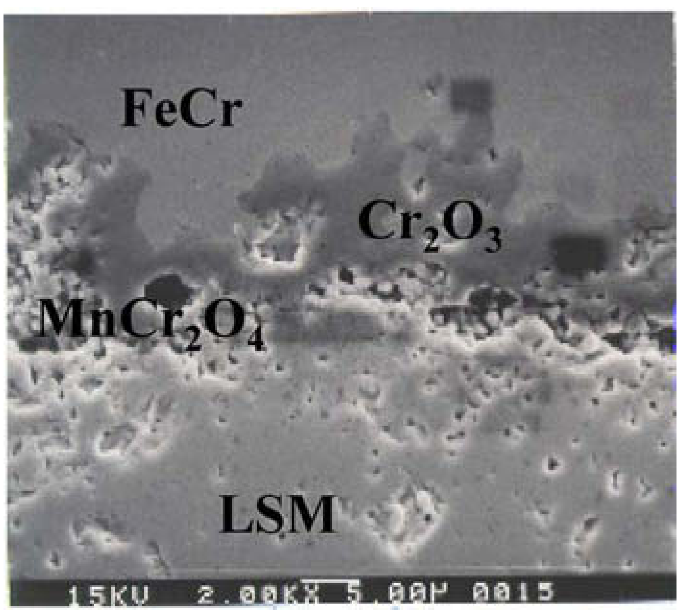

Figure 3: *SEM micrograph of polished cross-section of LSM/ FeCr interface showing the formation of $MnCr_2O_4$, and electronically conductive film that may prevent chromium evaporation from FeCr alloys in moist air.*

References

1. Selmar de Souza, Steven J. Visco, and Lutgard C. DeJonghe, "Reduced-Temperature Solid Oxide Fuel Cell Based on YSZ Thin-Film Electrolyte," *J. Electrochem. Soc.*, **144**, L35-L37, (1997).
2. Keqin Huang, Peggy Y. Hou and John B. Goodenough, "Reduced Area Specific Resistance for Iron-Based Metallic Interconnects by Surface Oxide Coatings," *Materials Research Bulletin*, **36**, 81-95, (2001).
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